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THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

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PLATE IV

ALL THOSE CONNECTED WITH THE PLAY

Behind (left to right): Bok, Miss Wright, Lindsey, Ransom, Miss Mohr, Shapley, Bowie, Miss Walker, Millman, Sayer, Campbell.
In front: Willis Shapley, Miss Shapley, Miss Ames, Miss Payne, Miss Swope, Miss S. Mussels, Miss Sawyer, Allan Shapley.
Absent: Miss Caldwell, Andrews, Wheelwright.

THE PRINCIPALS IN THE PLAY

Left to right: Bok, Miss Ames, Ransom, Campbell, Miss Payne, Millman.

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THE FORTY-THIRD MEETING OF THE AMERICAN ASTRONOMICAL SOCIETY

By R. MELDRUM STEWART

On the invitation of Harvard College Observatory, the forty-third meeting of the American Astronomical Society was held at Cambridge, Massachusetts, December 30, 1929 to January 2, 1930. Situated as it is within easy reach of the main intellectual centres of the eastern United States and Canada, and itself the home of one of the greatest observatories, few places are better suited for an astronomical meeting. To many of those attending, the only unfortunate circumstance was the necessity of being absent from home over the New Year. Perhaps to Canadians especially, with their more prevalent strain of Scottish tradition, this necessity brings regret; it is hard to see, however, how with a mid-week New Year's Day it can well be avoided.

At the opening session a cloud was cast over the assemblage by the announcement, then heard for the first time by a number of those present, of the death a few days earlier of Dr. Ralph H. Curtiss, Director of Detroit Observatories. The news came as a distinct shock; one's mind reverted unconsciously to the last meeting, at Ottawa, where his genial presence had been so welcome to all. His memory will long be with us.

All but one of the sessions for papers were held in the Jefferson Physical Laboratory, conveniently situated to the hotels and not far from the Observatory. The session of Tuesday afternoon was held,

on the invitation of Whitin Observatory, in one of the many well-equipped buildings of Wellesley College. The extent and beauty of the grounds of the College, as well as the number and variety of the imposing college buildings, elicited considerable comment. Before the session visitors were given an opportunity to inspect the observatory and its well-equipped laboratory. Later they were entertained to tea in the observatory residence by Director and Mrs. Duncan. Before returning to Cambridge those who so desired were afforded a glimpse of Wilk's comet through the observatory telescope. To a visitor from Ottawa, unconsciously expecting the opposite, the early onset of twilight at Wellesley was almost disconcerting; a consultation of the ephemeris, and verification of the longitude and consequent difference of local time, were necessary to the restoration of equanimity.

New Year's Eve was a red-letter event in the list of hospitalities provided. On that evening the Society was entertained in Harvard Observatory residence by Dr. and Mrs. Shapley. The *pièce de résistance* was a playlet written in 1879 by Professor Winslow Upton, and now presented for the first time by the observatory staff. As Dr. Shapley explained, the manuscript had been unearthed some years ago among observatory papers, and its authorship, though previously suspected, had been only that evening definitely verified through the presence of Mrs. Upton. The playlet, entitled The Harvard Observatory Pinafore, was a delightful adaptation of the well-known opera, first presented in 1878. Many of the characters were well-known members of the staff at the time of writing, and the songs had been cleverly re-written to the original music. The whole idea of the performance was so original and so well executed that the delight and enthusiasm of the audience were unbounded. "The fair Josephine" (otherwise Miss Cecilia H. Payne) was easily the star of the performance. The cast of characters, as printed and distributed to the guests, is given in facsimile herewith.

Subsequent to the afternoon session on Wednesday the members were entertained to tea by the officers of the Bond Astronomical Club. In the evening the usual society dinner was held at the Commander Hotel, at which President Brown presided in his usual happy manner. Incidentally, in the course of his remarks, the

The Harvard Observatory Pinafore

Written in 1879 (Probably by Winslow Upton)

Presented for the First Time by the Observatory Staff

TUESDAY, DECEMBER 31, 1929

Before the American Astronomical Society

Under the direction of Dr. Harlow Shapley and
Miss Helen Sawyer

.. *Program* ..

CAST OF CHARACTERS

Professor Arthur Searle, *in charge of Photometry* Leon Campbell
Mr. Winslow Upton, *Assistant Observer (on Photometer P)* G. W. Wheelwright
Professor William A. Rogers, *in charge of Meridian Circle* P. M. Millman
Miss Rhoda G. Saunders, *Computer* ..... Adelaide Ames
Joseph F. McCormack, *Circle Reader* ..... Cecelia H. Payne
Professor Edward C. Pickering, *The Director* ..... W. R. Ransom
Dr. Leonard Waldo, L.L.D., *Director of Observatory at Providence* ..... B. J. Bok
Mr. Frank E. Seagrave, *Gentleman from Providence* ... A. R. Sayer
Computers: Misses Irma Caldwell, Sylvia Mussells, Helen Sawyer, Mildred Shapley, and Henrietta Swope
Influential Men from Providence: Messrs. Bowie and Andrews

Costumes: Miss Henrietta Swope *Properties*: Miss Arville Walker
Conductor and Violinist: Miss Jenka Mohr
Pianist: Miss Frances Wright

Act I: Computing Room of Observatory. Early Morning.
Act II: Library of Observatory. Late Afternoon.

The Bill of the Play Presented Before the American Astronomical Society

chairman noted the fact that, of those at the head table, four were born under the British flag. Speeches were called for and responses made, partly in serious and partly in lighter vein, from Professor S. A. Mitchell, Miss A. H. Farnsworth, President of the American Association of Variable Star Observers, Professor H. H. Plaskett and Miss Cecilia Payne. The latter responded by wielding the baton for a re-rendition by the whole gathering of several of the songs which had delighted them the evening before.

Thursday morning was spent in a visit to the laboratories of the General Electric Company at West Lynn. Here naturally the phase of absorbing interest to astronomers was the work on fused quartz mirrors carried on under the direction of Dr. Elihu Thomson. The visitors were shown all the essential processes in the manufacture of optical disks, as well as a number of completed disks of various sizes. The main portion of each mirror consists of a block of fused quartz cast in an electric furnace. These blocks are cloudy and only translucent; though of smooth and uniform texture they are unsuited for polishing by reason of the multitude of minute air bubbles distributed throughout the mass, giving the characteristic milky appearance. The last stage in the process is the deposition of a layer of the required thickness, of clear fused quartz deposited by a battery of blow torches; this stage was actually witnessed in operation. The largest disk as yet made has a diameter of twenty-two inches; the next to be undertaken will be a sixty-inch, and the culminating stage is to be the two-hundred-inch blank for the projected new giant telescope of California. Few of those who participated in the inspection will have serious doubts as to the final accomplishment of the project.

The main business of the meeting was of course the reading and discussion of papers, of which thirty-one were presented. This occupied two morning and two afternoon sessions. As was perhaps to be expected at a Harvard meeting, over a third of the papers dealt with one phase or another of the study of variable stars, though most other main branches of astronomy were each represented by several papers. As is so often inevitable, discussion of interesting points had sometimes to be postponed for lack of time, to wax hot

later at informal gatherings. The suggestion was heard mooted that it might be a valuable experiment to restrict at least a part of the program to symposia consisting of invited papers, with, possibly, previously issued abstracts and sufficient time for prepared discussion.

The establishment of an information bureau was announced. The secretary will be prepared, on request, to disseminate such information as reaches him from time to time in regard to vacancies on astronomical staffs, as well as in regard to prospective candidates available for appointment. This, if properly taken advantage of, should prove a valuable feature; its success will naturally depend on the thoroughness with which the secretary is kept in touch with conditions. Those wishing to avail themselves of the service offered should write to Professor R. S. Dugan, Princeton University Observatory, Princeton, N. J.

It was announced that, on the invitation of Professor Fox, the summer meeting would be held at the Adler Planetarium, Chicago, at a date to be annoumnced later.

The program of papers, in the order of presentation, follows:

1. J. E. Willis: The crossed-vertical transit, a new instrument of fundamental astronomy.
2. J. W. Fecker: Work done to date on the 70-inch disk cast by the Bureau of Standards, Washington. (lantern)
3. H. D. Curtis: Some instrumental aids. (lantern)
   (a) A new type of comparator.
   (b) A set of permanent parallax sectors.
   (c) The Burns computing attachment for comparators.
   (d) The Allegheny Observatory instrument shop.
4. R. L. Waterfield: Total solar eclipse, May 9, 1929, observed in the Philippines. (lantern)
5. Frederic Slocum: Preliminary report on the probability of clear sky for the 1932 total eclipse of the sun. (lantern)
6. Alexander Vyssotsky: Photographic observations of Espin double stars. (lantern)
7. Piet Van De Kamp: A determination of the masses in the double star systems 99 Herculis and Beta 648. (lantern)
8. M. S. Kovalenko: Mass-ratio and relative proper motion of centre of gravity of 70 Ophiuchi.
9. M. Alberta Hawes: On the variation in wave-length of individual lines with spectral class from F to K. (lantern)

10. Otto Struve and C. T. Elvey: Note on the spectrum of Epsilon Aurigæ. (lantern)
11. E. F. Carpenter: Spectroscopic orbit of the eclipsing variable U Cephei. (lantern)
12. Svein Rosseland (introduced by Harlow Shapley): On the theory of stellar absorption lines.
13. J. Q. Stewart: Some restrictions on the application of the rocket principle to interplanetary travel. (lantern)
14. Harlow Shapley: Variable stars in the large Magellanic Cloud.
15. Henrietta H. Swope: Report on one thousand and one new variable stars.
16. Harlow Shapley and Helen B. Sawyer: Variable stars in globular clusters.
17. B. J. Bok (introduced by Harlow Shapley): The spectrum of Eta Carinæ.
18. B. P. Gerasimovic and Harlow Shapley: The color indices of long-period variables.
19. Annie J. Cannon: Omicron Ceti; photographic light curves and spectroscopic notes.
20. Leon Campbell and Cecilia H. Payne: Comparison of photographic and visual light curves of eight long-period variables.
21. Margaret L. Walton and Annie J. Cannon: Variations in the spectra of Cepheids of the international program.
22. L. V. Robinson: Photographic light curves of forty Cepheid variables.
23. Cecilia H. Payne: Cepheid spectra and the c-characteristic.
24. Knut Lundmark: Remarks concerning the extent of the universe.
25. E. W. Pike (introduced by R. S. Dugan): Mass-density relation. Notes on eclipsing variables. (lantern)
26. S. A. Mitchell: Allegheny and McCormick Parallaxes compared with spectroscopic. (lantern)
27. Knut Lundmark and Sten Asklof: New dynamical parallaxes of 600 stars computed.
28. N. W. Storer: Note on the eclipsing binary, Delta Orionis. (lantern)
29. H. T. Stetson and Margaret Olmstead: A further study of the variation in latitude of the moon's position. (lantern)
30. J. Q. Stewart: Possible repulsion of particles near stars due to the influence of non-isotropic evaporation.
31. Dirk Reuyl: Photographic measures of double stars.

THE CENTRAL SOLAR ECLIPSE OF APRIL 28, 1930

By R. M. Motherwell

The central solar eclipse of April 28, 1930, will be visible as an annular eclipse along a narrow path crossing southeastern Saskatchewan, Manitoba, and the northern parts of Ontario and Que-

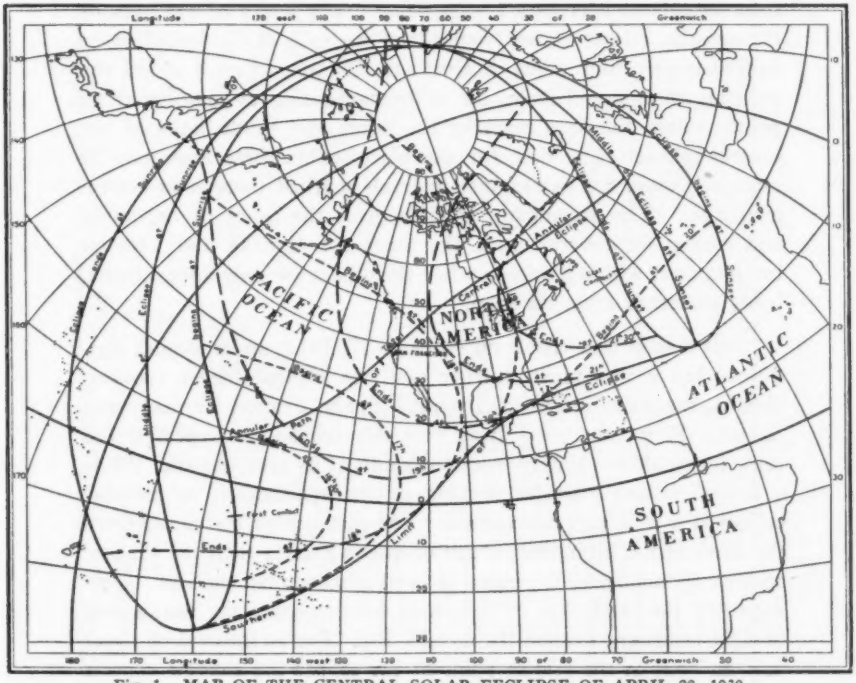


Fig. 1. MAP OF THE CENTRAL SOLAR EECLIPSE OF APRIL 28, 1930.
(From the *American Ephemeris*).

bec, ending in the north Atlantic Ocean. It will be visible as a partial eclipse in all other parts of Canada, about two-thirds of the Sun's surface being covered at Halifax and about four-fifths at Victoria.

The map (Fig. 1), taken from the American Ephemeris, gives the path and places of beginning and ending of partial eclipse for each hour. As indicated thereon, the eclipse will be total as seen along its path in the northwestern States. The duration of totality, however, will be very short, less than two seconds at its maximum. The annular eclipse will last less than three seconds at the boundary line between Canada and the United States but will last about fifteen seconds as it crosses Hudson Bay. The width of the path of the annular eclipse varies from about one mile at the boundary to approximately four miles in Northern Ontario. Fig. 2 shows the path on an enlarged scale, the eclipse appearing as annular at all points within the lines marking the north and south limits of the central eclipse. The time for any place within these lines may be estimated from the five-minute intervals marked thereon in central civil time. The accompanying table gives the times of beginning and ending for several cities, the times for Halifax and Victoria being correct within a minute while the others are only approximate, being estimated from the map.

This eclipse was visible on April 16-17, 1912, under similar conditions but it was much further east, the central eclipse crossing Guiana, the Atlantic Ocean, Portugal, Spain, France, Germany and Russia. Fifty-four years from now this eclipse will repeat at the same longitude but slightly north or south of its present path. While a partial eclipse provides nothing of the spectacular, an annular eclipse is a striking phenomenon. The distance of the moon from the earth at the beginning of this eclipse is greater than the shadow cone of the moon, so the moon appears smaller than the sun. Consequently the black disc of the moon fails to cover the sun, a ring of light remaining around the moon's disc. For an interval of about half an hour at the middle point of the eclipse the shadow cone is greater than the distance of the moon from the earth so the eclipse is then total. But the distance of the moon increases again and during the remaining interval the eclipse is annular. The extremely short duration of the eclipse, whether as total or annular, is due mainly to the fact that at no time during the eclipse is the point of the shadow cone of the moon far from the earth's surface. The

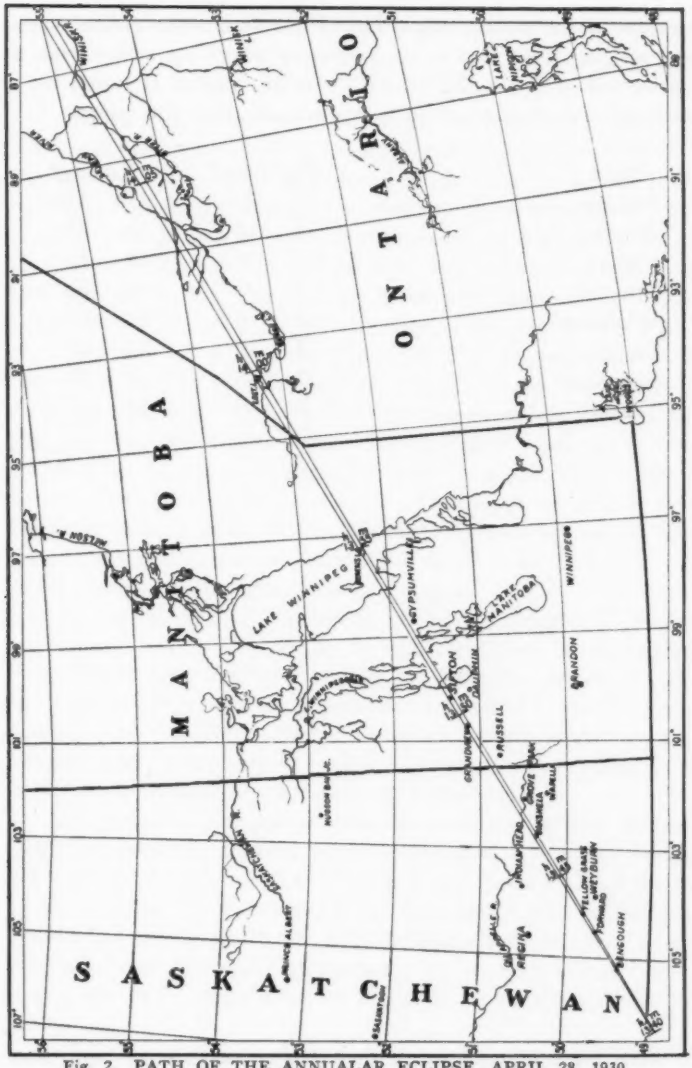


Fig. 2. PATH OF THE ANNUALAR ECLIPSE, APRIL 28, 1930.
The time of occurence is given in Central Standard Time.

duration of the partial eclipse has of course a much greater variation, ranging from zero at the beginning where the eclipse ends at sunrise and at the ending where the eclipse begins at sunset up to more than two hours and forty-five minutes near the centre.

Place	Beginning*	Ending*
Halifax	15h 28m	17h 41m
Montreal	14 12	16 33
Ottawa	14 10	16 33
Toronto	14 00	16 30
Winnipeg	12 18	15 03
Calgary	11 10	13 55
Edmonton	11 13	13 56
Victoria	9 58	12 36

*Time given is the Standard Civil Time numbering the hours from midnight.

STELLAGRAPHS: STAR PICTURES BY RADIO*

By D. R. P. Coats

Not all radio listeners are interested in the stars, of course, but some are, and many others would become so, if the subject of astronomy were suitably introduced to them. At various broadcasting stations with which I have been, and am associated, I have tried the experiment of teaching the names and forms of the principal groups of stars with the aid of a system which I have called "Stellagraphs". By this method, I have transmitted by radio a series of pictures of constellations, illustrating appropriate talks.

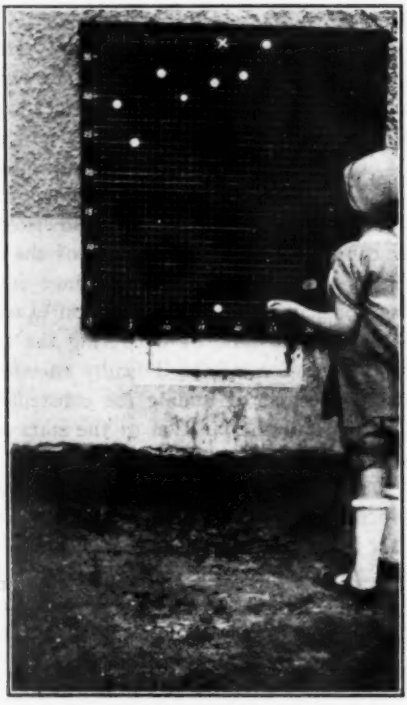
With the aid of squared paper, the radio listeners have been able to plot points representing the positions of the stars, and thus to follow the talks more easily. An important feature has been that each Stellagraph has shown a constellation exactly as it would be tilted in the sky at the time of delivering the talk, or shortly after. Thus has been overcome the difficulty encountered by every beginner in astronomy, that of finding the constellations by reference to maps, which show the position of the stars at certain fixed times, perhaps inconvenient for observation.

By this system of instruction, the student receives a number of formulae which can readily be converted into a Stellagraph. Immediately after hearing a talk, he can make his own chart and, if the night is clear, he can locate the stars referred to by the speaker without much trouble. Every school-boy knows something about graphs, and the plotting of points on squared paper. This is the basis of the system, hence the name, Stellagraphs.

In preparing a series of talks for broadcasting, the instructor applies transparent squared paper to standard star maps, pricking off each constellation in the position it will occupy when the talk is to be given. Commencing with the Dipper and including the point representing zenith, the first Stellagraph shows how to locate Polaris. With this as a starting point, we are then able to find our way from each constellation to the next as we proceed with the talks.

*Presented at the Winnipeg Centre of the R.A.S.C.

Making Stellagraphs is a fascinating occupation, for the instructor as well as for the student. Several hundreds of "solutions" have been received by mail, from children and adults, prov-



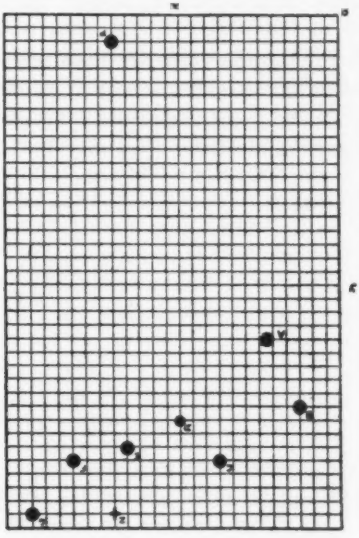
CHILD BUILDING A STELLAGRAPH

ing that the plan is thoroughly practicable. From time to time, prizes consisting of popular books on astronomy, have been offered for the neatest Stellagraphs submitted, and competition has been keen.

A CLASS-ROOM GAME

On numerous occasions, I have demonstrated the system at public

gatherings, using a blackboard divided into squares, and stars of appropriate sizes, representing the various magnitudes, made of card and attached to the board by means of push-pins. As the formula comes from the loud-speaker beside the blackboard, the demonstrator selects a cardboard star of the required magnitude, as indicated by the last figure in the code group, and pins it on the board at the point located by counting the squares horizontally and



STELLAGRAPH, MAY 1, 10.15-10.30 P.M.

vertically. As a game for Boy Scouts, this has possibilities. It is interesting to try it without previously mentioning the name of the constellation, offering a reward to the boy who first recognizes and names it during the building process.

Each group in the formula commences with a letter. This letter is to be marked on the chart against that particular star, for purposes of identification when the instructor proceeds to discuss the constellation. No attempt is made to follow the conventional order of lettering by the Greek alphabet as used by astronomers;

the stars are labelled merely for the convenience of the instructor and the student. When necessary, the Greek letters by which the various stars are known are stated in the course of the discussion. The points are accurate to the half square. Following is an example of a Stellagraph, showing the Dipper as it appears between 10.15 p.m. and 10.30 p.m. on May 1st, the observer facing North:

The formula would be broadcast thus:— A5.5x24y2 B3x29y2 C9x33y2 D12x30y3 E16x32y2 F20x33y2 G23x37y2 P17x2y2 Z17x37y (zenith).

A number of Stellagraph formulae have been prepared, showing the constellations on various dates, and at different times. I am considering publishing these and shall be glad to hear from teachers, scoutmasters, and others who may be interested.

CJRX, Winnipeg, Man.

ON THE VALUE OF π

The value of π, the ratio of the circumference of a circle to its diameter, occurs constantly in astronomical and physical problems. Most computers use the value $\pi = 3.14159$, which ordinarily is sufficiently accurate. Four-figure tables or slide rules are generally used in solving problems in physics and chemistry. In astronomical problems, seven-figure tables, corresponding to an accuracy of 0″.01 are constantly used in the determination of the orbits of comets and asteroids, although five-figure tables which give the second of arc, such as Hussey's, are used for all ordinary work.

The novice is frequently guilty of using the fraction 22/7 as an approximation for π, although this value is incorrect in the fourth-figure. I do not think it is generally known 355/113 is a splendid approximation for π. This fraction is only out 3 in the seventh decimal place and is therefore more correct than 3.14159. Moreover, it is easy to remember from the sequence of figures 113355.

In the October, 1929, issue of *The Observatory*, we read in the "Oxford Note-Book" the well-known French sentence, which is useful in remembering the value of π to the eleventh significant figure;

> "Que j'aime à faire apprendre un
> nombre utile aux sages."

The suggestion is there made that the Editors offer a prize for the best English sentence giving the value of π. The first proposal comes from the author of the "Note-Book";—

> "How I love a great meteorite in
> August skies all black."

(of course the slight slip in the sixth word is quite excusable.)

The following sentence was told to the writer by a member of the Victoria Centre, R.A.S.C., some months ago;

> "How I wish I could recollect of circle
> round, the exact relation Arkimedes found."

This is strikingly similar to the French sentence, and extends the accuracy two figures, if the spelling of Archimedes is permitted.

We should point out, however, that the last word is incorrect, as the value of π to the sixteenth figure is 3.14159 26535 89793.

Perhaps some of our readers can supply the three missing links. It is suggested that the expressions

$$\frac{\pi}{4} = 2\tan^{-1}\frac{1}{3} + \tan^{-1}\frac{1}{7}$$

$$= \tan^{-1}\frac{1}{2} + \tan^{-1}\frac{1}{5} + \tan^{-1}\frac{1}{8}$$

be used to compute π, if anyone is interested in adding further lines to this rhyme. These expressions were used by Clausen and Dase to compute π out to 200 figures (see *A.N.*, No. 589). Mr. Rutherford used the expression

$$\frac{\pi}{4} = 4\tan^{-1}\frac{1}{5} - \tan^{-1}\frac{1}{70} + \tan^{-1}\frac{1}{99}$$

but unfortunately his value was erroneous beyond the 150th figure (Chauvenet: "Plane and Spherical Trigonometry", p. 125).

J. A. P.

THE EARTH BENEATH IN THE LIGHT OF MODERN SEISMOLOGY[1]

By Ernest A. Hodgson

The Earth is an object of special interest to all of us. We are, indeed, attracted to it much more strongly than to any other of the heavenly bodies, of which, we must remember, it is one. For the votaries of Urania to turn from their contemplation of *The Heavens Above* to a consideration of *The Earth Beneath* is in no sense to depart from their allegiance to the Muse of Astronomy. We need not seek to justify the propriety of presenting an address on seismology before an audience of the Royal Astronomical Society of Canada.

A variety of circumstances make this place peculiarly appropriate for such a subject. We are met under the auspices of a Society which has published more articles on seismology than any other in this country. We enjoy the hospitality of a University whose former President—Dr. J. W. (later Sir William) Dawson—made the first statistical studies of Canadian earthquakes[2]. The lecture room is one of those assigned to the Department of Physics, one of whose early professors—Dr. Smallwood—operated, as long ago as 1870, what was presumably the first seismograph to be set up on this continent[3].

We are gathered on the flank of an extinct volcano, but on a rock foundation so solid that we should be comparatively safe in any sort of earthquake we may reasonably expect to experience in Canada. Yet, within a mile of this place, we can find conditions of unstable soil, coupled with old or shoddy workmanship which would certainly be dangerous were we to experience now an earthquake as severe, say, as that which on September 5, 1732, damaged some three hundred houses in Montreal alone, resulted in the death of at least one, and the injury of many under circumstances overwhelmingly less likely to prove serious than those which obtain in the same locality to-day. Those engaged in construction work in this country will some day more generally consider the known precautions with regard to earthquake tremors which should be ob-

served in varying degree depending on the nature of the ground concerned.

Our subject is not earthquakes, however, but the earth. Astronomy first taught us something of our earth as a whole. That science was partly responsible for, and greatly assisted the voyage of Columbus which demonstrated that one could cross the Atlantic without, at least, falling *off*. The idea that the earth is spherical is now general except in Zion City, Illinois. Astronomy measures for us the radius of our planet, finding it to be about 4,000 miles, the circumference being nearly 25,000 miles. Astronomy mothered Geodesy which has demonstrated that the earth is a spheroid *of the oblate order*. The remark about the orange which invariably follows in the school books leaves one with an uneasy sense of a religious controversy in this connection.

The shape and size of the earth being known, Mathematical Physics, also an offspring of Astronomy, informs us that the average density of the earth is 5.6 (in c.g.s. units). It weighs, therefore, volume for volume, five and six-tenths times as much as water. This statement may be taken as a convenient cross-over to Geology. Physics and allied sciences are able to tell us only *average* values for conditions within the earth; the *average density*, the *elasticity as a whole*, the *mean value of gravity;* the details are notably lacking. The geologist is concerned with surficial *details*. Informed that the earth, as a whole, weighs a little more than five and a half times as much as an equal volume of water, he states that the granite, marble, limestone, dolomite, etc., which form the bulk of our surface rocks weigh only about half as much, volume for volume, as the earth as a whole and that therefore there must be much denser material below. The questions throng: how far down do the surface rocks extend? what distribution of densities exists within the earth? in what physical state do the materials exist, solid, liquid, or gas? We are curious to investigate what lies within *The Earth Beneath*.

The miner has the terse expression, "Beyond the pick it is dark"[4]. If this be so, how far may we penetrate below the surface. The deepest mine in the world[5] is the Saint John del Rey, in Brazil. This gold mine was begun in 1834. In 1924, it had reached a depth

of 6,726 feet. The bottom of this mine is not, however, the point nearest the centre of the earth to which man has penetrated. The Calumet and Hecla mines in Michigan, though only about 6,000 feet deep, reach a horizon 4,600 feet below sea level, said to be the point nearest the centre of the earth on which man has been able to tread. The South American mines being in the mountains, their greater depth of shaft does not penetrate so far below sea level. Representing the radius of the earth by a line 120 miles in length—the distance from Montreal to Ottawa—the bottom of the Michigan mines lies at a point only 138 feet away. The number of deep mines or deep bores is small, their cost is enormous. To what depth have you personally inspected the interior of the earth?

If Physics deals with generalities, Geology studies details,—but practically only surface details as we have said. True, time has broken and uptilted parts of the earth's crust, exposing at the surface that which must once have lain at considerable depth. True, also, volcanoes bring up materials from below, though from what depths these materials come is not so well defined as we could wish. The geologist, having studied the earth's surface features admits that so far as he can learn the average density of the surface crust is only about half as great as that of the earth as a whole. We leave him as he argues from the known to the unknown, from the observed to the conjectured, from the fact that near the surface the temperature increases about 1° Fahr. for each 90 feet in depth to the possibility that at a depth of 40 miles the temperature may be about 2300° Fahr. or the "white heat of the blacksmith's forge,"[6] from measures of the elasticity and compressibility of rocks under high pressures in the laboratory to conjectures as to their properties at great depths within the earth.[7] We turn to Seismology for the decisive tests of any theory as to the structure of the earth on which we live and move and have our being; from which we get our means of livelihood, within which we find our final resting place; the fortress of mystery which man has, at last, completely surrounded, but which he has never penetrated, nor ever shall.

For some, an earthquake is a rare phenomenon of passing, if for the moment absorbing, interest: for others it is a dreaded nightmare of horror. To the engineer, it is a factor in his problems

of design; to the insurance agent and the financier alike, it is a risk; to the newspaper man, it means business; to the geologist, it is a tectonic agent; to the seismologist, it is all of these and more.

Our subject requires us to consider the earthquake as a release of energy—the agent which despatches a signal to be registered on the seismograph set up at each of a net-work of stations distributed over the globe. The signals are there recorded after having traversed the earth for various distances and along various paths; after having penetrated to various depths. The nature of the records indicates the paths by which the signals reached the instrument, the properties of the materials through which they passed. They are thus worthy of the greatest care in our choice of the net-work of stations, our design of instruments and vaults, our maintenance of continuous recording and accurate timing, our thoughtful study. These constitute the *Modern Seismology*, in the light of which we are to view the *Earth Beneath*.

Our first problem may be stated thus,—At what depth do earthquakes release their signals? Some undoubtedly occur on the surface, though, presumably, the casual movements extend deep into the earth. Others leave no traces of permanent shift at the surface. The added fact that they are sensibly felt over wide areas indicates that they originate far below. We can arrive at a conclusion with regard to depth of focus, as it is called, along different lines of reasoning. Dutton[8] used as a means of determining depth a consideration of the rate at which the intensity falls off as the disturbance spreads out in all directions from the focus and makes its effects apparent at the surface. He concludes that the *maximum* depth of focus is of the order of 20 miles. Walker,[9] working with Galitzin's measures of the angle at which the seismic rays emerge from the earth at the different stations in the vicinity of the focus, deduces that the depth of focus is of the order of one-fifth the earth's radius—800 miles! Omori,[10] making use of the duration of the preliminary tremors of earthquake records deduces that the mean depth of earthquakes in the Kwanto province of Japan is of the order of 21 miles. Gutenberg[11] studied the curve showing the time of arrival of the first tremors and determined for an earthquake in the Schwabian Alps a depth of 34 miles. A recent paper by

Wadati[12] deals very thoroughly with the various methods. He finds that the Japanese earthquakes fall into two groups, which he terms respectively shallow and deep. "The deep earthquakes take place at the depth of more than 300 km. (186 miles), while the shallow ones at about 40 km. (25 miles)." Gutenberg, in a publication which has just issued from the press,[13] tabulates the values of depth of focus as determined by nine different seismologists for sixteen different earthquakes. With the single exception of Wadati's deep earthquakes, the determinations all lie at depths of 28 miles or less. Seismologists generally agree that the data for determining the depth of focus are not as precise as could be desired but that earthquakes probably originate, in general, at depths of 25 miles or less.

The uncertainty with regard to the depth of focus is due largely to our uncertainty as to the velocity of propagation of the seismic waves in the uppermost layer of the earth's crust. To determine this velocity we must have an earthquake of which we know, accurately, the time of occurrence and the depth of focus. We can be sure of this last requirement only where the depth is zero, *i.e.*, where the focus is at the surface. On February 18, 1911, a disturbance was registered which was traced to the Pamirs, in central Turkestan. Investigation showed that a great slide had occurred in which from 7 to 10 billion metric tonnes of rock had fallen a distance of from 400 to 800 yards. The tremors, registered on the seismographs at Ottawa and generally throughout the world, were believed to have been the result of the rock fall.[14] The exact time of the fall could not be determined. Moreover it is now questioned whether the fall was the cause or the result of the earthquake.[15] Such a question could be raised in the case of practically any such earthquake. We fall back upon the velocity of earth tremors generated by an explosion.

The velocity of seismic waves has been studied in the case of a great explosion at Oppau, in the works of the Badische Analin und Sodafabrik in the Bavarian Palatinate on September 21, 1921.[16] The tremors were registered at five seismograph stations ranging in distance from 68 miles to 227 miles. The chord from Oppau to De Bilt—the farthest station—dips only about two miles below the surface at the middle of the arc. We may thus consider the waves

as being well within the upper layer of the earth. The exact time of the explosion is known within one second. The records give the velocity of propagation of the most rapid tremors as 5.4 km. (3.35 miles) per second.

But one swallow does not make a summer. It was desirable to check the value of the velocity by means of other explosion records, especially as the velocity as determined for waves generated by earthquakes of presumably shallow focus was found to be 7.1 km. (4.4 miles) per second. Accordingly, in May, 1924,[17] four explosions, the first two of ten metric tonnes each, of melinite, the second two of five metric tonnes each, were exploded at La Courtine, in central France. The explosions being predetermined, arrangements were made to have precise timing and fast-speed chronographs, so that the records obtained were spread out sufficiently to be readily legible. The tremors were registered at three stations ranging in distance from three and a half to fifteen and a half miles. The mean value of the determined velocity for the most rapid tremors was found to be 5.5 km. (3.4 miles) per second, confirming substantially the results obtained from the records of the Oppau explosion.

This raises a further point. We have referred only to the velocities of the first movement as registered on the seismograph. The fact that high-speed chronographs were used at La Courtine to spread out the record implies that there were other onsets of value. There were.

Waves propagated in an elastic body (that is to say, a substance which has the power of recovering its shape if it is not strained beyond certain limits—and the earth is such a body) are of two kinds. The first is known as a longtitudinal or dilatational type and the waves so propagated are called P-waves, since they are the primary or first registered. The other type is called transverse or distortional, the waves being termed S-waves, because they are the secondary registration, in point of time. The P-wave and the S-wave each travel through the earth from the focus to the station, by paths which may be for the present described as being somewhat concave upward, or as sagging below the chordal line joining the focus and the station. The velocity of each depends on the

elastic properties of the earth, being greater, in each case, if the elasticity of the material along the path increases, but slowing down for an increase in density. The S-wave has the added important characteristic that *it cannot be propagated through a liquid.*

The velocity of the first, fast tremor, found to be 5.4 km. (3.35 miles) per second in the case of the Oppau explosion, and 5.5 km. (3.4 miles) per second, on the average, at La Courtine, was that of the longtitudinal vibrations—the so-called P-wave. The velocity of the S-wave was found to be 3.1 km. (1.9 miles) per second at Oppau and 2.8 km. (1.7 miles) per second in the mean at La Courtine—again a fair agreement. We thus have a measure of the velocity of propagation of the two types of waves in the uppermost layers of the earth's crust, based on observations of five separate explosions, registered at three or more stations in each case. Obviously we wish to add to our observational data of this nature.

To quote from our legal friends, "time is to be the essence" of our experiments. The nearest of the La Courtine stations was three and a half miles from the blast. The first tremor, marking the time of arrival of the P-wave, registered about one second after the explosion. The S-wave required about two seconds to travel the same distance. The difference in time of arrival was thus about one second in the case of the nearest station, and about four seconds in the case of the farthest. To render the onset of the S-wave legible it was necessary to record the tremors at a higher speed than that generally used for earthquakes. Obviously, if the distance is increased to several hundreds or thousands of miles the difference in time of arrival will be increased and, moreover, slight inaccuracies in the determination of the exact instant of arrival of either phase will not greatly affect the velocity determination.

In order to convey some idea of the manner in which the two types of waves make their appearance on a seismogram, the two groups of records of Figure 1 are shown. The arrival of P and S is indicated for the two seismograms of the first group. These are records registered at Jena and Göttingen respectively—two German stations about 80 miles apart—of an earthquake which occurred at Kansu, China, about 4,600 miles from the recording stations. One

minute of record line is indicated at the beginning of the record and successive minutes can be seen on the original records as breaks in the line, a few of which are preserved even in the reproduction. The difference in time of arrival of S and P is here about 8 minutes and 50 seconds. To obtain a record such as this a line recording speed of from half an inch to an inch and a half per *minute* would ordinarily be employed, depending on the seismograph used and the

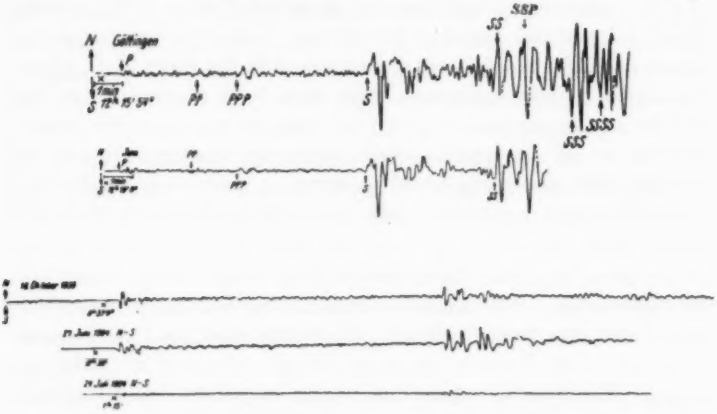


Fig. 1. (*Upper group*): Seismograms registered at Gœttingen and Jena, respectively, of an earthquake in Kansu, China, 1920, December 16.
(*Lower group*): Seismograms registered at Jena, of earthquakes in Kamchatka, on the dates indicated.
(This illustration has been copied from Gutenberg's discussion of "Fernbeben," in Borntraeger's "Handbuch der Geophysik." See footnote 13).

purpose of the registration. Where S and P arrive within a second or so of each other, as in the case of a blast or explosion, it is customary to have a line recording speed of six or seven inches per *second*. Such a short-distance, but spread out record would resemble those registered at Göttingen and Jena for the Kansu quake except that the serrations would be more numerous.

The second group of records is also interesting. It shows the seismograms registered at Jena for three earthquakes, each of which originated in Kamchatka—about 5,300 miles distant—in October, 1920, June, 1924, and July, 1924, respectively. This shows how strikingly alike are the records of the same instrument for earthquakes originating at the same epicentre.

A friend of mine, a devotee of bridge, sometimes mutters a brief prayer in the words, "through strength and up to weakness." Let us repeat this solemn incantation now in order that you may be properly impressed with the strength of that part of seismology which has become so well established that it now forms the strong supporting column of the seismological attack on the problem of the internal structure of the earth. If, at the close of this address, you feel that the van of that attack is occupying ground which it may not be able to hold indefinitely, do not forget that all will not be lost in any event. We are sure of some things—and rather interesting and somewhat surprising things they are too.

We know, from long experience, that if an earthquake takes place as a sharp, well-defined, single shock, it will be registered at stations which are more than 700 miles and less than 7,000 miles distant in such a manner that the arrival times of P and S can be definitely determined, the difference computed, and the distance from station to epicentre (that point on the surface vertically above the focus) read off from an empirical table or its graph to within twenty-five or fifty miles. Furthermore, we can, if the stations are equipped with proper apparatus for recording absolute time, determine the time at the epicentre so accurately that the values derived from the records of stations at distances within the above limits will agree within a few seconds. Moreover, the distances from each of three or more stations being known, for any given earthquake, the position of the epicentre can be determined with a surprising degree of accuracy. And, finally, this work has been done, with ever increasing accuracy, by various agencies since 1899, supplementing previous catalogues of felt earthquakes and giving us an analysis of the relative seismicity of the different parts of the earth's surface, which is very good indeed. This analysis is being continuously strengthened to-day by the efforts of over two hundred stations, regularly operating seismographs and publishing data. Our time distance curves are subject to but minor corrections for distances between 700 miles and 7,000 miles. We know our seismic areas. The seismic history of many of these areas is already long-continued enough to be of value in various lines of investigation. From this hard-won, but firmly consolidated position we step for-

ward into the front-line trenches, the active sector of seismological research.

To detail the various investigations which combine to give us our present tentative conception of the internal structure of the earth is beyond the limits of this address. It must suffice that, after outlining that conception, the seismological evidence supporting it be briefly inspected. The methods adopted for checking the details of the proposed earth structure will serve to give us some idea of the procedure by which that structure has been inferred.

All seismologists agree that the earth has a spherically layered structure, consisting of a central core surrounded by a series of shells of different thickness, each with its own distinct properties. The spherical surfaces separating the various shells are probably fairly well defined, that is to say the transition is relatively sudden. They are referred to as surfaces of discontinuity, or simply as discontinuities.

Let us consider first the central core. The surface of discontinuity surrounding it is believed to lie about 2,900 km. (1,800 miles) beneath our feet, or a little less than half the distance to the centre of the earth. The material of the core is believed to be iron, with probably some nickel as well. If our earth is made of the stuff of which other worlds are made, (and that seems a reasonable assumption) and if the meteors which occasionally fall to the earth are to be regarded as samples of that material then we may infer a mixture of iron and nickel for the central core. Here we have a large part of the extra density demanded by the physicist to make up for the light surface rocks and average up the density of the earth to the 5.6 which he demands. The existence of the core is rather well established. The P-waves are refracted into its surface in such a manner that they fail to reach stations which are between 7,000 miles and 10,000 miles of the epicentre leaving the so-called blind zone as shown in Figure 2.

In what state is the iron of the core—solid, liquid, or gas? The question is still an open one. The fact that the S-wave will not be transmitted through a liquid or a gas suggests that we apply that criterion. This is not as easy as might be supposed. Some seismologists believe the S-wave has been identified after transmission

through the core, most are agreed, however, that it has not been positively identified, and some are frankly of the opinion that the central core is liquid or gas. It is supposed to be dense, under high pressure of course, but not an elastic solid. The velocity of the P-wave is high for the layer just outside the central core—about 13. km. (8 miles) per second. Within the core it drops suddenly to 8.5 km. (5.3 miles) per second. Does the density suddenly increase as you pass into the core, or does the elasticity become markedly less? Always we are left with questions, unanswered as yet but not unanswerable. Of such is the kingdom of research.

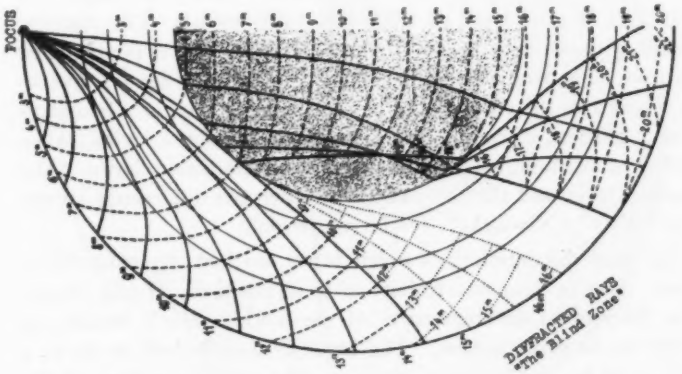


Fig. 2. Cross-section through the earth, showing the path of propagation of characteristic longitudinal waves.
(Adapted from Gutenberg's contribution to Borntraeger's "Handbuch der Geophysik." See footnoe 13.)

Without them we should develop an orthodoxy of science which would be fatal.

The surface of discontinuity at the central core is, as has been noted, well-defined. It is indicated by the "blind zone" and also by the sudden drop in velocity which, in turn, indicates either a sudden increase in density or a rapid falling off in elasticity or a combination of these. The fact that there is a sudden drop in velocity is deduced mathematically from the observational data of earthquake records—the so-called time-distance or traveltime curves. A paper by Knott[18] presents the method by which this is done. A

recent book by Gutenberg (Pages 32-80 of reference 13) outlines the work of recent writers on this subject. There is no other such well-marked sudden change of velocity with increase in depth as that which occurs at the entrance to the core. The other changes are less abrupt and are, in general, *increases* in velocity. The other discontinuities are thus not so well established, in fact or in position as is that at about half way down the earth's radius.

Ascending from the 2,900 km. level we traverse, in turn, three layers of slightly different properties, the two discontinuities separating them being so ill-defined that we are not sure where—or even whether—they are. The discontinuity which surrounds the triple layer is at a depth of 1,200 km. (750 miles). The material composing these three layers is supposed to be silicon impregnated with iron. The iron content is supposed to increase for points successively nearer the core, and to be very small at the outer boundary at the 1,200 km. discontinuity. The three ill-defined layers, taken together, constitute what is known as the transition layer. The transition layer and the core, taken together, are sometimes known as the "Nife" (Ni=nickel: fe=ferrum=iron).

The next discontinuity is much better marked; its existence is certain; there is some uncertainity as to its position. It may chance to be different in different parts of the world. Much remains to be done in its investigation. The break is usually held to be at a depth of 60 km. (37 miles). It marks the upper boundary of the shell of silica and magnesium usually designated as the "Sima" (the name indicating the constituents). The increase in velocity with depth within this layer is so uniform that it is not believed to suffer any internal discontinuities. The density inevitably increases somewhat with depth due to the superimposed weight; the elasticity must thus gradually increase downward at a fairly uniform rate in the Sima, and at a less regular rate in the transitional layer of the Nife until finally we get the great reversal, the fall in velocity, at the central core. Let us come back toward the surface and nearer home. What is the constitution of the upper 60 km. (37 miles) of the earth's crust?

Jeffreys[19] believes that there are three layers, separated by discontinuities at depths of 12 km. (7.5 miles) and 37 km. (23 miles).

These he terms, in order descending, the granitic layer, the basaltic layer, and the ultrabasic layer, thus indicating the probable nature of their constituent rocks. The three taken together are known as the "Sial" (Si=silicon: al=aluminum).

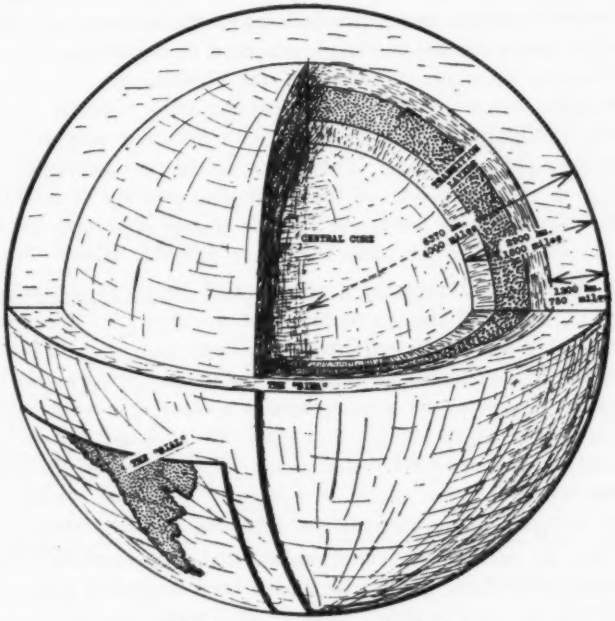


Fig. 3. The structure of the earth.

To sum up then, beginning at the surface and continuing downward we have, in order,—a layer of granitic rock 12 km. (7.5 miles) in thickness; 25 km. (15.5 miles) thickness of basalt; a 23 km. (14 miles) layer of ultrabasic rocks; 1,140 km. (700 miles) of silicon-magnesium—the Sima; a transition layer of silicon impregnated with iron, of a total thickness of 1,700 km. (1,060 miles); and, finally, a great nickel-iron core of radius 3,470 km. (2150 miles). The best marked discontinuities are those at 60 km. and at 2,900 km.

Figure 3 shows in schematic form the various layers.

The discontinuities about which we should most like to know

more are those at 12 km., 37 km., and 60 km. We shall learn more about them only through a study of earthquake waves and waves generated by explosions. If you look over the edge and into a cup, diagonally so as to just miss seeing a coin placed in the bottom of the cup at the side nearest, and then pour water into the cup, the coin becomes visible, due to the bending of the light ray as it passes from the water into the air—a phenomenon of ***refraction***. The echo is a familiar example, in sound, of the phenomenon of *reflection*. Earthquake waves are refracted in passing from material of given density and elasticity into a second with different properties, *i.e.*, in crossing a discontinuity. They are reflected on reaching the surface or at the inner side of the great discontinuity at 2,900 km. depth. Seismologists name the various phases appearing on their records according to the paths they have probably taken. For example $\overline{S_cP_c}\ \overline{P_cS}$ represents a wave which began as a transverse vibration, traversed the discontinuity at the core $(_c)$; went on as a P-wave but was totally reflected at the inner face of the 2,900 km. discontinuity; proceeded as P; again traversed the core and completed its journey to the seismograph as a transverse wave. Figure 2 shows some of the waves going directly through the core, refracted but not reflected. These are designated the P′ waves. Where reflection takes place, bars above the letters bracket each leg of the path, as indicated in the extended symbol above.

Near the surface we have a multiplicity of refractions. Figure 4 shows some of the paths which have been suggested as possible.

It will be seen that we have a very large number of wave arrivals on our seismogram—at least that we may expect many. As a matter of fact some arrive with such small energy content that they register but faintly. This, nevertheless, affords a further check on the theory, as that theory attempts to predict which waves should register thus. The proposed structure may thus be checked in many ways by means of longtitudinal and transverse internal or body waves of earthquakes. We have not mentioned that there are also two types at least, of surface waves. These also serve to throw light on the study of the outer earth shells. Time fails for us to enter on a discussion of what is known as seismic prospecting, by means of which commercial interests probe the upper 4000 feet or so of

the earth's crust in the search for oils and minerals. They delineate many of the details of the upper layers, but, from a purely scientific standpoint, the most interesting result is the large mass of data showing the relation of the wave velocity and the type of material traversed.

We have outlined, then, the present theory of the structure of the interior of the earth and indicated the means by which it is to be

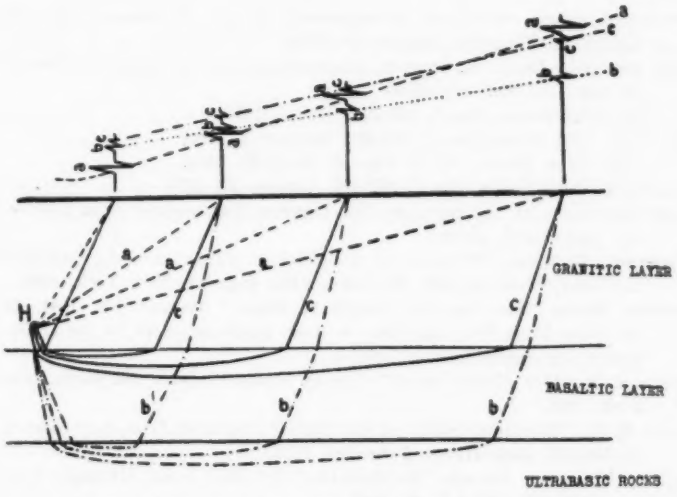


Fig. 4. Diagram of the paths of propagation of the longitudinal waves through the upper layers of the earth.
(After Gutenberg.13)

checked and improved through a study of seismic waves. If a later modification of the theory should give traveltime curves more nearly in accord with later and more accurate data, the modification will be adopted. The present theory is (in the language of the automobile prospectus) the latest model, which we take pleasure in exhibiting at this time. We hope it will find its way into the hands of many and that they may enjoy the fullest service in its use. It may be traded in as soon as suggested improvements have been found worthy of adoption. All may rest assured that *when better theories*

of the internal structure of the earth are built, seismology will build them.

Dominion Observatory,
Ottawa, Canada.
October 30, 1929.

FOOTNOTES

[1]Presented before the Royal Astronomical Society of Canada, Montreal Centre, on Thursday, October 31, 1929.

[2]Four papers by Dr. J. W. Dawson, which appeared in the *Canadian Naturalist and Geologist*, as follows:
(i) Old Series, No. 1, 189-196, May 1, 1856.
(ii) Old Series, No. 5, 363-372, October 17, 1860.
(iii) New Series, No. 1, 156-159, April 20, 1864.
(iv) New Series, No. 7, 282-289, October 20, 1870.

[3]Last three lines of the paper by Dr. Dawson, last mentioned in footnote (2) immediately above.

[4]Ambronn, Richard, "Elements of Geophysics," (Translation by Margaret C. Cobb), McGraw Hill, 372 pages (See page 1), New York, 1928.

[5]Science News, "The Age and Depth of Mines," *Science*, No. 1541, *60*, viii, New York, July 11, 1924. A short article prepared by the United States Department of the Interior.

[6]Daly, R. A., "Our Mobile Earth," Charles Scribner's Sons, 342 pages, New York, 1926.

[7]Daly, R. A., "The Outer Shells of the Earth," *American Journal of Science, 15*, 108-135, New Haven, February, 1928.

[8]Dutton, Clarence Edward, "Earthquakes," Putnam's Sons, 314 pages (See pages 185-193), New York, 1904.

[9]Walker, George W., "The Problem of Finite Focal Depth Revealed by Seismometers," *Philosophical Transactions of the Royal Society of London*, Series A, *222*, 45-56, August 5, 1921.

[10]Omori, Fusakichi, "On the Focal Depth of the Earthquakes Originating in the Kwanto Province," *Journal of Geography, 34*, 237-241, Tokyo, 1922.

[11]Gutenberg, B., "Neue Methoden zur Bestimmung der Herdtiefe von Erdbeben aus Aufzeichnungen an Herdnähegelegenen Stationen," *Zeitschrift für Geophysik 1*, Heft 3, 65-75, Göttingen, 1923.

[12]Wadati, K., "Shallow and Deep Earthquakes," *Geophysical Magazine, 1*, No. 4, 162-202, Tokyo, 1928.

[13]Gutenberg, B., "Theorie der Erdbebenwellen," Gebrüder Borntræger, (Handbuch der Geophysik, *4*, Lieferung 1), 298 pages (See page 234), Berlin, 1929.

[14]KLOTZ, OTTO, "The Earthquake of February 18, 1911, (A discussion of this earthquake by Prince Galitzin with comments thereon)," *Journal of the Royal Astronomical Society of Canada, 9,* No. 428-437, Toronto, November, 1915. (See also footnote 16.)

[15]MACELWANE, JAMES B., S.J., "Are Important Earthquakes Ever Caused by Impact?" *Bulletin of the Seismological Society of America, 16,* No. 1, 15-18, Stanford, March, 1926.

[16]JEFFREYS, HAROLD, "The Earth," Cambridge University Press, 278 pages (See pages 169-170), 1924.

[17]MAURAIN, CHARLES, EBLE, L., and LABROUSTE, H., "Sur les ondes sismiques des explosions de la Courtine," *Le Journal de Physique et le Radium, 6,* No. 3, 65-78, Paris, March, 1925.

[18]KNOTT, C. G., "The Propagation of Earthquake Waves Through the Earth and Connected Problems," *Proceedings of the Royal Society of Edinburgh, 39,* Part 2, No. 14, 157-208, 1918-1919.

[19]JEFFREYS, HAROLD, "On Near Earthquakes," *Monthly Notices of the Royal Astronomical Society, Geophysical Supplement, 1,* No. 8, 385-402, London, December, 1926.

[20]SIEBERG, A., et al., "Geologische, physikalische und angewandte Erdbebenkunde," Gustav Fischer, 572 pages, Jena, 1923.

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Ottawa.

ETHER DRIFT EXPERIMENTS IN 1929 AND OTHER EVIDENCES OF SOLAR MOTION*

By Dayton C. Miller

The ether-drift interferometer, previously used on Mount Wilson in California from 1921 to 1928, has been remounted on the campus at Case School of Applied Science, Cleveland. Some minor improvements have been adopted, such as shock-absorbing pads on the supporting piers, to eliminate traffic vibrations, and added precautions have been taken to eliminate temperature disturbances. The methods of making and reducing observations are so devised as to remove the possibility of instrumental or terrestrial disturbances, and the observed effects seem to be cosmic in origin. As before, the interferometer has a sensitiveness represented by a light path of 214 feet, or about 130,000,000 wave-lengths of light. The numerical results are reliable to the hundredth part of a wave-length of light, corresponding to one-half of a kilometer per second of relative motion of the earth and the ether. A series of experiments recently completed gives results wholly in accord with those previously obtained at Mount Wilson; the observed effect is such as would be produced by a relative motion of the earth and ether of about ten kilometers per second. The direction of the indicated motion is fixed with relation to sidereal time; that is, it is towards a fixed point in space, as of a motion of the solar system towards the point having a right ascension of seventeen hours, and a declination of 68 degrees north. Ether drift produces an effect as observed in the interferometer which is proportional to the square of the ratio of the velocity of the cosmic motion of the earth and the velocity of light; this is a "second order" effect, and is periodic in each half revolution of the interferometer. The complete theory of this experiment shows that there is necessarily also present a "first order" effect periodic in each full turn of the interferometer; this has never

*Abstract of a paper presented to the National Academy of Science, Washington, D.C., December 6, 1929.

before been taken into account. But it is now shown that this effect is always present and that it is in accord with the theory, and it is considered a further evidence of the validity of the present experimental results. It seems impossible at the present time to account for a cosmic effect of this small magnitude, and it will be necessary to continue these experiments and to coordinate them with others before an acceptable theory can be propounded. It is interesting to note that the present interferometer is mounted about three hundred feet from the location of the original Michelson-Morley interferometer of 1887, and that the magnitude of the observed effect is almost exactly the same as that obtained by them. The recent results, therefore, notwithstanding a prevalent opinion to the contrary, fully agree with and conform the original Michelson-Morley observations, though the present interpretation is different. Attention is called for the first time to the results of several recent important experiments in diverse fields which seem to corroborate the indicated cosmic motion of the solar system. Meridian circle observations of star places made by direct and reflected rays show peculiarities which are explained by assuming a motion of the solar system towards the sidereal time meridian of about seventeen hours. This effect has been found by the independent observations of Courvoirsier (Berlin) and of Esclangon (director of the Paris Observatory). Esclangon finds evidence of similar motion in observations of lunar occultations of stars, and still more convincingly in elaborate studies of earth tides (deformation of the earth's crust) and of ocean tides. In the latter work, he considered 166,500 observations, extending over a period of nineteen years. The well-known study of radial and proper motion of stars in our own galaxy by Campbell (Lick Observatory) and by Wilson (Dudley Observatory) give a motion of the solar system towards the constellation Hercules, of eighteen hours right ascension. Stromberg (Mount Wilson Observatory), from an investigation of clusters and nebulae, finds evidence of a motion of the solar system with its apex at twenty-one hours right ascension and declination of 56 degrees north. By a study of the reflection of light, Esclangon finds strong evidence for what he calls an "optical dissymmetry of space" with its axis of

symmetry in the meridian of twenty hours sidereal time. This effect would be explained by an ether drift, and the results are in striking agreement with the ether-drift observations here reported. Many recent observations on cosmic rays show a very definite maximum of radiation coming from the direction indicated by the meridian of seventeen hours sidereal time. The very extensive observations of Kolhorster and Von Salis, and Weld and of Steinke, all show this effect. Observations made on the non-magnetic ship *Carnegie* show a maximum at seventeen hours sidereal time for the observations made between 30 degrees north and 30 degrees south latitude. There are several anomalies in astronomical observations of less definite character, which, however, might be explained by the existence of an ether drift. Such anomalies occur in connection with the observed constant of aberration, standard star places and clock corrections determined at different times of day. There are at least twelve different experimental evidences of a cosmic motion of the solar system, all indicating the same general direction, and ten of them show a motion towards a right ascension lying between sixteen and one-half hours and eighteen hours. Seven of these investigations give the declination as well as the right ascension, and thus determine the apex of the motion of the solar system. The various apexes all lie within a circle on the celestial sphere having a radius of 20 degrees. This is a remarkable agreement considering the nature of the various observations involved.

SUBATOMIC ENERGY AND STELLAR RADIATION*

A recent paper by Gerasimovic and Menzel has introduced a new idea which may be of considerable importance in the interpretation of various phenomena connected with the source of stellar energy. It is generally believed that in some way, subatomic energy provides the source from which comes the energy radiated by the stars. The precise mechanism responsible for the liberation of this energy is not fully understood. Millikan and Cameron suggest that the building up of heavier elements from hydrogen nuclei is responsible for the penetrating cosmic radiation; and similar processes may take place in the interiors of stars. Jeans assumes the annihilation of protons by bound electrons falling into the nuclei of atoms of high atomic weight. There is also the possibility of collisions of free electrons and protons, a process demanding the existence of electrons moving with every high velocities.

These processes have two important characteristics in common: (a) They all result in the transformation of matter into radiation, and (b) they are quantum phenomena and as such are presumably subject to laws similar to those governing other better known quantum processes. Since such quantum transformations as the absorption and emission of radiation and ionization and recapture are reversible in character and can proceed in either direction, the conclusion is drawn that the transformation of matter into energy is also a reversible process and that the opposite transition, the generation of matter, may also take place in stellar interiors.

According to this theory, the total radiation of a star is not a measure of the rate of transformation of mass into energy but rather represents the excess of the process over the opposite process of generation of matter. The rate at which a star radiates will then depend on whether or not conditions in the stellar interior are such as to favour these reverse processes. It is well-known that the radiation of energy per unit mass is greater for giant than for dwarf stars. An examination of the data discloses the fact that the rate of radiation is a function of the density and that the denser

*Seminar Talk, D.A.O., Victoria.

the star the smaller the amount of radiation emitted per gram. Gerasimovic and Menzel explain this by assuming that under conditions of low stellar density the transformation of Mars into energy shows a large excess over the coupled process, generation of matter. In stars of high density conditions are more favourable for the generation of matter and as a consequence the excess energy available for radiation is less.

Necessity for postulating exhaustion of the source of energy was one of the most formidable difficulties encountered by the theories of Eddington and Jeans. The new theory denies that there is any exhaustion (except the inevitable slow loss of mass) and points to the varying physical conditions in the stellar interior as the cause of the changes in the rate of radiation.

The actual mechanism responsible for these transformations is still a matter for speculation. Gerasimovic and Menzel postulate certain deviations from thermodynamic equilibrium in the stellar interior, making possible the existence of electrons with speeds approaching that of light and quanta with correspondingly large amounts of energy. The collisions of high speed electrons with protons maintains the supply of high energy quanta and the interaction of these quanta with slow speed electrons replenish the supply of electrons with speeds approaching that of light. The process, once started, may be self maintaining. It is of course understood that in addition to collisions of free electrons with protons producing high energy quanta, a collision between an electron and a quantum may result in the formation of matter.

C. S. Beals.

REVIEW OF PUBLICATIONS

Modern Cosmologies: a Historical Sketch of Researches and Theories concerning the Structure of the Universe, by Hector Macpherson. 131 pages, 4¾ x 7 in. London and Toronto: Oxford University Press, 1929. Price $2.25.

The author of this book is favourably known as a well-informed student of astronomy and a scholarly writer. It consists of eight lectures delivered in Glasgow during the winter 1928-29. The subjects treated are: the geocentric cosmology, the heliocentric cosmology, Herschel's cosmology, nineteenth century cosmological thought, twentieth century progress, the local cluster, the status of the nebulæ, the globular clusters—satellites of the Galaxy, island universes.

This is a large programme but within the compass of the small volume the essential features of each system of cosmology are indicated as well as their significance in the development of our views on the nature of the universe.

The present writer knows of no other book in which so clear an outline of the ideas of the universe enunciated during successive centuries are so clearly sketched, and references to original publications on the various subjects are given.

In illustrating how far we have expanded our notions during the last four hundred years the following paragraph may be quoted from the last page of the text:

"In 1529 the world was homely and comprehensible to a degree —a central earth for the benefit of whose inhahibtants the whole of the universe had been constructed, with sun, moon, and stars moving round it to minister to their needs. The universe of 1929, even if finite, extends to 600 times 140 million times six billion miles! Certainly if this is finitude it is a kind of finitude which bludgeons the mind into stupefaction."

As stated by the author, in 1900 the estimated diameter of our galaxy was 6,000 light-years, which itself is very considerable; but in thirty years this has expanded fifty-fold, as Shapley's value is given as 300,000 light-years. What will be the estimated size in 1960?

C. A. C.

NEWS AND COMMENTS

Dr. Asaph Hall, of the U. S. Naval Observatory, who retired from a professorship of mathematics in the U. S. Navy on June 30 of last year, died on January 12 in his seventy-first year. Professor Hall achieved great fame through his discovery in 1877 of the two tiny moons of Mars.

Following the lamented death of R. H. Curtiss, Dr. W. Carl Rufus has been appointed chairman of the Department of Astronomy and acting director of the Observatory, University of Michigan. Dr. Rufus has been connected with the University since 1913.

With the approval of the Council of the American Astronomical Society, Professor R. S. Dugan, secretary, has undertaken to provide a service for information regarding positions vacant or positions desired by astronomers. It is to be hoped that those interested will communicate with Professor Dugan, Princeton University, N.J.

Professor F. J. M. Stratton, of the astrophysics department in the University of Cambridge, has been appointed acting general secretary of the British Association for the Advancement of Science, succeeding Dr. F. E. Smith who recently retired, for the period before the meeting of the association next autumn in Bristol.

Mr. J. E. Umbach, C.E., D.L.S., Surveyor-General of British Columbia, member of the Council of the Victoria Centre of the Royal Astronomical Society of Canada, and formerly on the staff of the Topographical Surveys, Ottawa, died suddenly on February 2, while on board steamer to Victoria, returning from a trip to Ottawa.

Dr. A. S. Eddington, Plumian professor of astronomy at Cambridge University, was elected president of the Mathematical Association, London, at the Annual Meeting on January 6.

"Cosmical or Comical?—'The all enveloping and motion developing sunstream, which is tremendously practical as well as romantic in its operation, like unto a gigantic blanket belt that is pivoted upon a ponderous anodic axis, diurnally projects pulsating

and cathodic electronic filiaments multifarious into the component worlds of solar space subdivisional'."—From "Cosmic Causes" by Frederick A. Baker, quoted in the *Citizen,* Ottawa.

Professor to astronomy class in the dome.—"As I came in I saw Aurora Borealis all lit up."

Freshette.—"Yes, these foreigners are getting drunk all the time."

As stated in the last issue, Professor C. A. Chant is collecting observations of the bright meteor seen on the morning of January 3, 1930. He has a large number of reports from Ontario and some from the United States. Professor Dean C. McLaughlin of the University of Michigan, Ann Arbor, observed the mirror himself and is also collecting information. It is stated that the meteor was particularly brilliant in the neighborhood of Harrisville, Pa., but there is no report of it having been found. REDel.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

THE R. A. S. GOLD MEDAL

A brief note in our last issue intimated that the gold medal of the Royal Astronomical Society (of London) had been awarded to Dr. J. S. Plaskett, the director of the Dominion Astrophysical Observatory at Victoria, B.C. The reason given for the award is, "for his valuable observations of stellar radial velocities and the important conclusions derived from them." Along with this award the Society chose Dr. Plaskett to deliver the George Darwin Lecture. It will be given at the ordinary meeting of the Society on May 8, and the subject will be, "The High Temperature Stars." In this field of research Dr. Plaskett has been working for some eight years.

The lecture is delivered annually in memory of Sir George Darwin, second son of Charles Darwin and a well-known mathematical astronomer.

Dr. and Mrs. Plaskett will leave Victoria about April 10 and will sail from Boston on the 27th. He will be one of the leaders in a symposium on Astronomy at a special meeting of the American Philosophical Society in Philadelphia on April 24-26. Professor Brown will speak on the Variable Rotation of the Earth, Dr. Plaskett on the Rotation of the Galaxy, Dr. Shapley on Other Galaxies, and a fourth (name not yet announced) on the Physics of a Star.

The gold medal of the Royal Astronomical Society was established in 1824 and distinguished astronomers from various countries have received it. Among them may be mentioned: J. Herschel (1826, 1836), Bessel (1829, 1841), Airy (1833, 1846), O. Struve (1850), Adams (1866), Leverrier (1868, 1876), Huggins (1867, 1885), Gill (1882, 1908), E. C. Pickering (1886, 1901), Hale (1904), Campbell (1906), Russell (1921), Dyson (1925), Einstein (1926), Schlesinger (1927), Sampson (1928), Hertzsprung (1929).

This award is a great compliment to Canadian astronomy. Dr. Plaskett obtained the B.A. degree from the University of Toronto in 1899. He was appointed to the Dominion Observatory at Ottawa in 1905 when that institution was in course of construction, and on its completion he was placed in charge of the astrophysics section. He made excellent use of the 15-inch refractor, and realizing that it was too small for the best results in this branch of astronomy he began a campaign to secure a larger one. In this he had good support, but largely through his initiative the Federal Government ordered the 72-inch reflector at Victoria. It began work in 1918 and in the few years since then the director and his able staff have made many important researches.

PROFESSOR MITCHELL'S GREAT ACHIEVEMENT

Professor S. A. Mitchell, director of the Leander McCormick Observatory of the University of Virginia, recently paid a visit to the city of Kingston, Ont., where he was born and educated. He had just come from a meeting of leading astronomers of the eastern

states held at Yale University where he was specially honoured on his completion of the measurement of 1,000 stellar parallaxes.

As is well known, the first parallax was measured in 1838 and in the sixty years following hardly one star was added per year, while the results obtained by different observers for the same star were often discordant. Then the photographic method was introduced and in the hands of Schlesinger when at the Yerkes Observatory it became efficient and remarkably accurate. On his appointment to Allegheny, Dr. Schlesinger continued the work, and under Dr. H. D. Curtiss it is still proceeding.

There are six observatories paying considerable attention to this branch of astronomy. Besides the McCormick, Yerkes and Allegheny observatories, already mentioned, special attention to it is given at Mt. Wilson, Sproul and Greenwich. McCormick has 1,000 stars to its credit, Allegheny 805, and the remaining four (with a few from other institutions) have measured 1,400, making a total of 3,200. There are many measurements of the same star and the net results is about 2,000 stars.

The trigonometric method used in this work is the only direct way to obtain stellar parallax. The spectroscopic and other methods all are based on the results of the trigonometric method. Few people have any idea of the care, skill, patience and eternal vigilance demanded in this delicate work and the world is greatly indebted to those who are working so persistently in this field of astronomy which has no spectacular features.

USE OF SPIDER'S THREAD

In a recent number of *Natural Resources, Canada,* published by the Canadian Government, was an interesting account of the use of spider's thread by the surveyor and astronomer. Included was a description of the method of obtaining this fine fibre which I give herewith.

Secreted in the body of the spider is a fluid, which crystallizes upon exposure to the air. This hardened fluid constitues the thread. Sufficient fluid for the spinning of a surprising length of thread—stronger than the same thickness of silk—is contained within the body of the spider.

At the Physical Testing Laboratory of the Topographical Survey,

Ottawa, many yards of spider thread are used during the year in the overhauling of the Government's survey equipment. In the early fall an instrument maker visits the green-houses at the Central Experimental Farm and returns with five or six spiders of medium size and of a mottled grey colour. One at a time these spiders are made to run about on a wooden stick until their web has adhered to the stick. The stick is then gently tapped until the spider falls, spinning a strand from the stick as he does so. This thread, which is under tension of the spider's own weight, is wound on wire forks which have been given a light coat of shellac to hold the strands in place. These forks are then stored away until the thread is required.

RETIREMENT OF DR. BAUER

The present writer was sorry to learn that on account of ill health Dr. Louis A. Bauer, director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington since the establishment of the department on April 1, 1904, retired from this position on January 1, 1930. He has been given the title of director emeritus, and if his health permits will carry on studies as a research associate of the Institution. Dr. Bauer has certainly been an efficient director and the results obtained during the last quarter century are of the highest importance to science and to practical navigation. Mr. John A. Fleming, who has been associated with Dr. Bauer since 1904 will conduct the work of the department with the title of acting director.

THE PLANET JUPITER

Jupiter is still a bright object in the evening sky and will be favourably placed for observation for some months. In the *Astronomical Notes* of the New Zealand Astronomical Society for December, 1929, is an interesting article on the planet written by Mr. E. G. Hogg, a portion of which I take the liberty of printing below.

The Planet Itself

Let us now gather up the salient facts concerning Jupiter—the giant planet of our system. Its mean diameter is no less than 86,500 miles, or eleven times that of the earth, and its volume is 1309 times that of our globe; its mean density is 1.38, or very nearly the same as that of the sun; its mass

is 310 times that of the earth. Jupiter rotates on its axis once in 9hrs 55min, so that a fixed point on its equator is moving at the rate of 95 miles a minute; it revolves about the sun once in 11.86 years at a mean distance of about 483 million miles; it has nine satellites, seven of which move round their primary directly, while the two outermost have retrograde motion.

The telescope reveals that the planet's surface is crossed by a series of markings parallel to the equator, which are evidently bands of clouds of a darker or lighter shade, but it is by no means clear why some of them should be so much brighter than others. Observation shows that the time of rotation at the equator is about five minutes less than at the poles, but it is the speed of the clouds that is measured, and not that of the surface of the planet itself, which is entirely hidden by the overlying masses of vapour. The different cloud-belts which encircle Jupiter are known as the equatorial current, north tropical current, and so on; these may be termed the permanent markings, though they are liable to variations in their widths and speeds of rotation. We have here many meteorological problems awaiting solution.

The Great Red Spot

In addition to the cloud-bands which even a small telescope will reveal, there are other markings of a semi-permanent character, the most noticeable of which is the great red spot which appears to have first shown up very conspicuously in 1878; it is described as covering an area of 30,000 miles long by 7000 broad, and being of a brick-red colour. It has faded somewhat of recent years, and has become rounder in shape. It was at one time regarded as the summit of some feature firmly attached to the planet, but the observations of the last thirty years show that it had moved over 20,000 miles in longtitude and many thousand miles in latitude; it would appear to be a gaseous concentration existing in the upper atmosphere of the planet, but we do not know to what it owes its colour, and how it is able to maintain its coherence.

In the belt just south of the red spot is a dark region called the south tropical disturbance, which has persisted since 1901; it moves relatively to the red spot, which it overtakes at intervals of two years, streaming by it at the rate of 16 miles an hour. As it goes by the red spot the latter appears to be dragged bodily in the direction of the neighbouring current through several thousand miles, dropping back after the passage is completed. It is evident that both these markings are floating in a fluid medium, and not rooted to anything solid within the planet.

The Atmosphere of Jupiter.

The quick movements of these and similar markings suggest that there is a vigorous circulation in the Jovian atmosphere, with rapid exchange of material between the visible surface and the underlying depths. The radia-

tion we receive from the planet is almost entirely reflected solar radiation, and the measurements of Coblentz and others show that the temperature of the reflecting material is about 220 degrees Fahrenheit below freezing point—a result from which it has been inferred that but little heat gets into the planet's upper atmosphere from an internal source. At the same time, it is difficult to understand how the comparatively small amount of heat received from the sun can bring about the observed atmospheric commotions.

The Constitution of Jupiter.

It is possible that the inner part of the planet is very hot and even gaseous, like the sun, but if, as is very probable, Jupiter is as old as the earth, it is difficult to see how it can have escaped cooling sufficiently to liquefy or even solidify during the long period of its existence. It has indeed been suggested by Dr. H. Jeffreys that the planet must have lost practically all its original heat by this time, and that its present constitution is a core of dense rocky material surrounded by a deep layer of ice and then by an extensive atmosphere. This theory does not at all commend itself to those who have watched the planet continuously for many years, and are well acquainted with the varied appearances it presents; these have been impressed above all things by the turbulence of its atmosphere and the violent movements therein, and they feel that any adequate explanation of the observed phenomena must be based upon an internal source of heat. Here we must leave the subject; we may have to wait long for the solution of the many intricate problems Jupiter affords, but increased knowledge will only heighten the delight we experience in it as one of the most beautiful spectacles the heavens can show us. C. A. C.

MEETINGS OF THE SOCIETY

AT OTTAWA

On Friday evening, January 24th, an open meeting was held in the lecture hall of the Victoria Memorial Museum. The President, Mr. C. C. Smith, was in the chair.

Before the lecture of the evening, Dr. F. C. Henroteau spoke a few words and showed slides of interesting objects now visible in the sky. Mr. Smith then introduced the lecturer, John Patterson, M.A., director of the Meteorological Service of Canada. Mr. Patterson's subject was "Meteorology in Northern Canada," and his address was illustrated with numerous maps and diagrams.

The lecturer did not deal with the climate of northern Canada, but rather the effect that is produced by having that vast cold area to the north of us. In reference to northern temperatures, it is of interest to remark that the coldest place is not at the pole but in the Province of Yakutsk, Siberia, at a latitude of 67°, where the average mean temperature for January is 60° below zero; while the average for January at Chesterfield Inlet on the northwest coast of Hudson Bay, is 35° below zero—and this is the coldest area in the northern part of the western hemisphere.

With these brief remarks, Mr. Patterson then passed on to discuss conditions which produce different types of weather. He said that little is known of the operation of the forces with which the meteorologist has to deal. Sir Napier Shaw compared them to an atmospheric or moist engine, the essential parts being a boiler, condenser, a working substance and a fly-wheel. Sir Napier considered the tropics as the boiler where the water is evaporated, the polar regions as the condenser, the winds around the globe as the fly-wheel and the working substance that part of the atmosphere from the surface to what is known as the tropopause—the surface where the temperature ceases to fall and above which it becomes warmer. The height of the tropopause decreases from the equator to the pole, the temperature becoming higher. No air can penetrate through it because air to rise must expand and so become colder, but as the air at these elevations is warm it is not possible for it to rise, thus there is no cloud, and no vertical current in the stratosphere.

Great mountain ranges have considerable influence on weather conditions, for instance the Rocky Mountains shut off the moist Pacific currents and radically modify the climate of the prairies.

Meteorological conditions in northern Canada have assumed new importance in the light of recent meteorological developments, and Mr. Patter-

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The objects of the Society, incorporated in 1890, are:

(*a*) "To study Astronomy, Astrophysics and such cognate subjects as shall be approved of by the Society and as shall, in its opinion, tend to the better consideration and elucidation of Astronomical and Astrophysical problems; and to diffuse theoretical and practical knowledge with respect to such subjects.

(*b*) To publish from time to time the results of the work of the Society; and,

(*c*) To acquire and maintain a Library, and such apparatus and real and personal property as may be necessary and convenient for the carrying into effect of the objects of the Society."

For many years the Toronto organization existed alone, but now the Society is national in extent, having active Centres in Montreal, P.Q.; Ottawa, Ont.; Toronto, Ont.; London, Ont.; Winnipeg, Man.; and Victoria, B.C. Among its 800 members are a number of the leading astronomers and scientists of the world, many amateurs, and in addition, many laymen who are interested in the culture of the science.

Membership in the Society is open to anyone interested in Astronomy. The annual dues are $2.00; life membership $25.00 (no further dues). The annual fee includes subscription to the publications.

The Society publishes a monthly JOURNAL containing about 500 pages of interesting articles, and the yearly HANDBOOK of 72 pages containing valuable information for the amateur observer. Single copies of the JOURNAL or HANDBOOK are 25 cents.

The Library and the Offices of the Society are at 198 College St., Toronto, Ont. Applications for membership, or for further information should be addressed to:

General Secretary—Dr. Lachlan Gilchrist, 198 College St., Toronto, Ont.

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